Identification and Removal of Bright Galactic Binaries from LISA's Data

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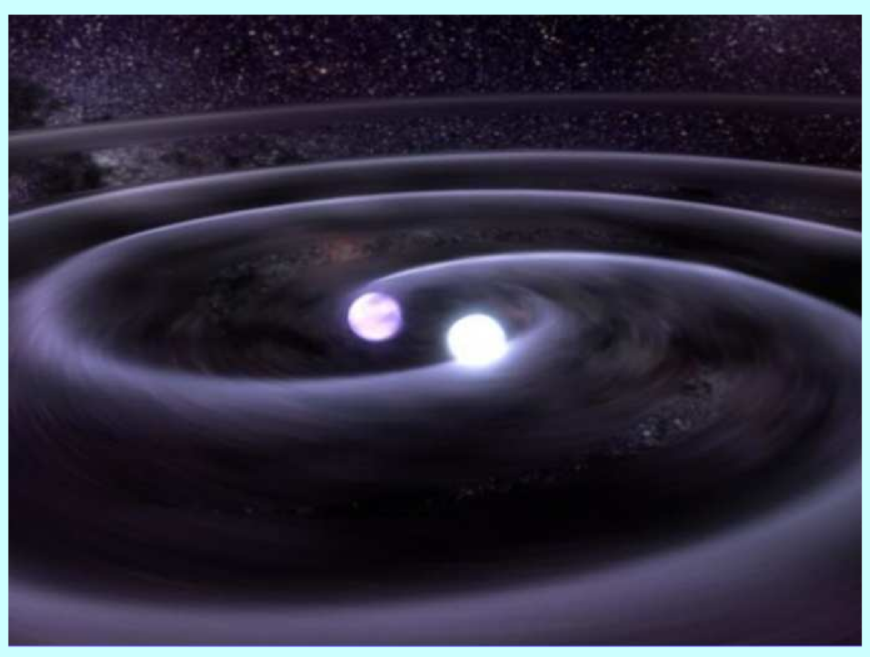
Within the Laser Interferometer Space Antenna (LISA) band there will be tens of thousands of quasi-monochromatic galactic binaries. The galactic binary population will form a confusion limited background below which individual systems cannot be distinguish from the collective population. Above the galactic background will be a few thousand relatively "bright" binaries, which due to their larger signal-to-noise ratios, can be individually resolved. However, significant correlations may still exist between the bright systems, which in turn will require unique data analysis techniques capable of resolving the individual systems.

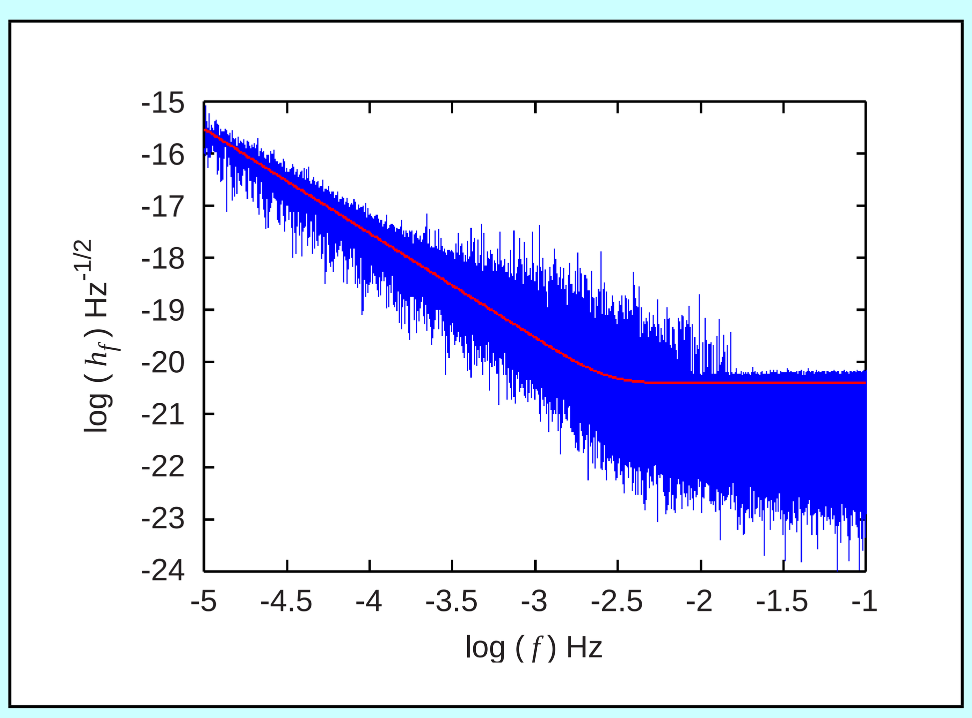
Here we describe a hierarchal and iterative data analysis algorithm used for searching, characterizing, and removing the bright monochromatic binaries from the LISA data streams. The algorithm uses an $\mathcal{F}$-statistic as an initial solution finder followed by an iterative least squares fitting which refines the parameter estimates. Using the above algorithm, referred to as Slice & Dice, we demonstrate the removal of multiple correlated galactic binaries from simulated LISA data. Initial results indicate that Slice & Dice may be a useful tool for analyzing the forthcoming LISA data.

Galactic Background

LISA will observe $\sim 10^8$ galactic compact binaries, the majority of which will be composed of white dwarf – white dwarf pairs. Of these, $\sim 10^4$ will be individually resolved within the LISA data.



The below plot shows the spectral amplitudes from a galactic background simulation based on population models from Hils et al. [1]. The simulation includes the detector response per source, in addition to an instrumental noise realization [2].



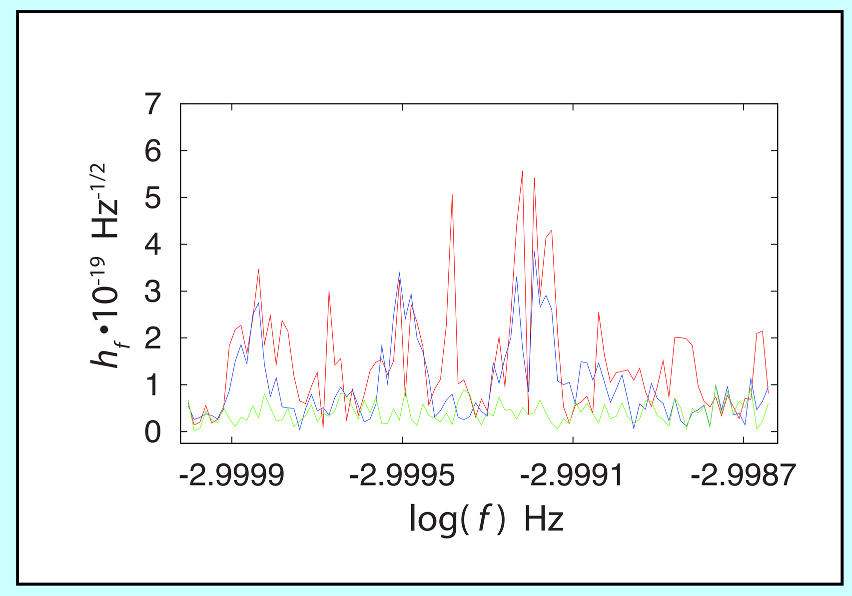
The galactic background is evident by the highly sporatic data between 10^{-4} and 10^{-2} Hz. For reference, the red line is the average instrumental noise (acceleration plus position noise).

The large spectral fluctuations are due to individual bright signals. These bright systems are the target signals for our Slice & Dice algorithm.

Identification and Subtraction Order

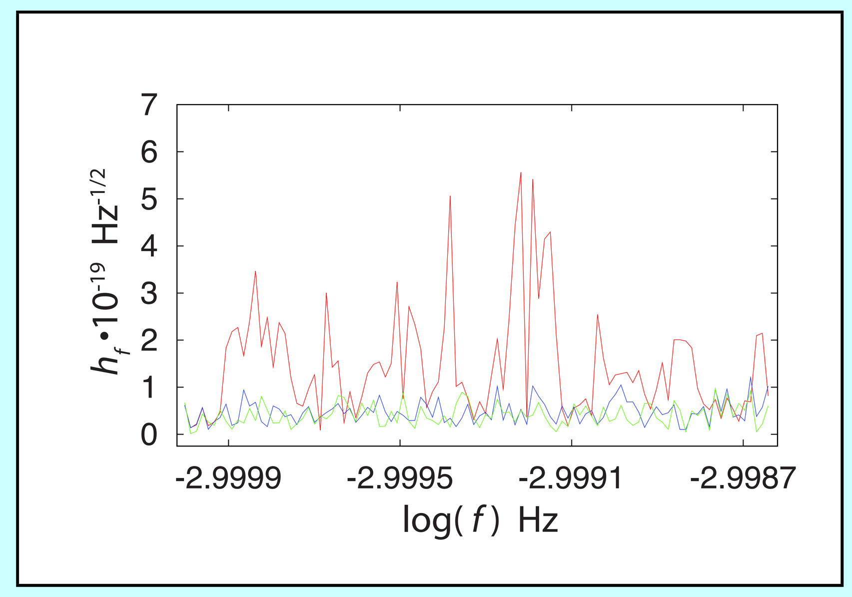
Template matching and least squares fitting provide a powerful approach to identifying and subtracting signals from LISA's data. However, when dealing with multiple signals simultaneously the order of identification and removal is crucial.

The adjacent plot shows the spectral amplitudes for a sequential identification followed by group removal using a template matching scheme on twenty signals. The red line is the original data, the green is the instrumental noise, and the blue is the residue after subtraction.



This approach fails because the algorithm treats the other bright signals as noise while it attempts to fit for one.

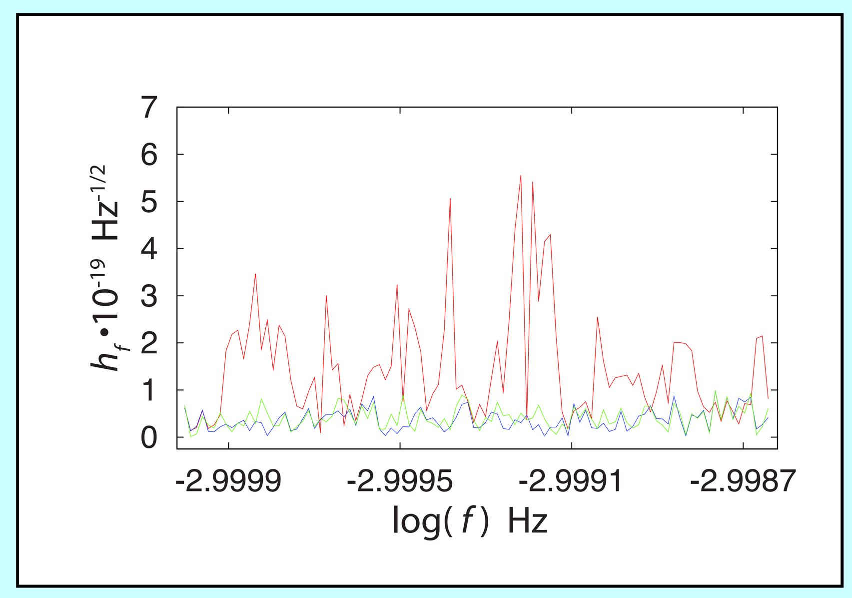
The next plot shows a sequential fit and removal procedure where the order of fitting and removal is based on the signal-to-noise ratios.



Although the residue looks reasonable, a comparison of the fitted signals to the original injections indicates that the weaker signals were not properly identified.

As with before, the interference from the other bright signals as the algorithm tries to fit one source causes errors, which ultimately propagate through to the fits for the weaker sources due to the intermediate subtractions.

The final plot demonstrates the results from performing a simultaneous fitting and removal scheme using a least squares routine initiated at the true parameter values.



In this case there are acceptable fits for each signal. However, for larger data sets the total number of parameters make this approach impractical for a straightforward template matching scheme. Moreover, a least squares fitting procedure is dependent on an initial guess.

Slice & Dice is able to simultaneously fit multiple signals using a combined template matching and least squares fitting scheme, while circumnavigating the traditional large template bank problem and providing initial guesses for the least squares.

Slice & Dice Algorithm

The Slice & Dice algorithm is an iterative routine that uses multiple LISA data streams.

Each iteration involves the following steps:

1. An $\mathcal{F}$-statistic (i.e., a template based) search is used to find the brightest signal and return an initial estimate for its parameter values.
2. The $\mathcal{F}$-statistic parameter estimates, along with previous iteration estimates, are used to initiate a least squares fitting routine that simultaneously solves for i signals, where i is the iteration number.
3. The least square routine is repeated until the change in the χ^2 is insignificant. At each least square cycle the initial parameter value guesses are supplied from the previous iteration.
4. The estimated signals are subtracted from the original data streams.

These steps are repeated until each of the bright sources (signal-to-noise > 5) are identified and removed.

Future Considerations

Slice & Dice currently works on a small segment of the gravitational wave spectrum. In the future we will expand and automate the algorithm so that it can take the full bandwidth of data.

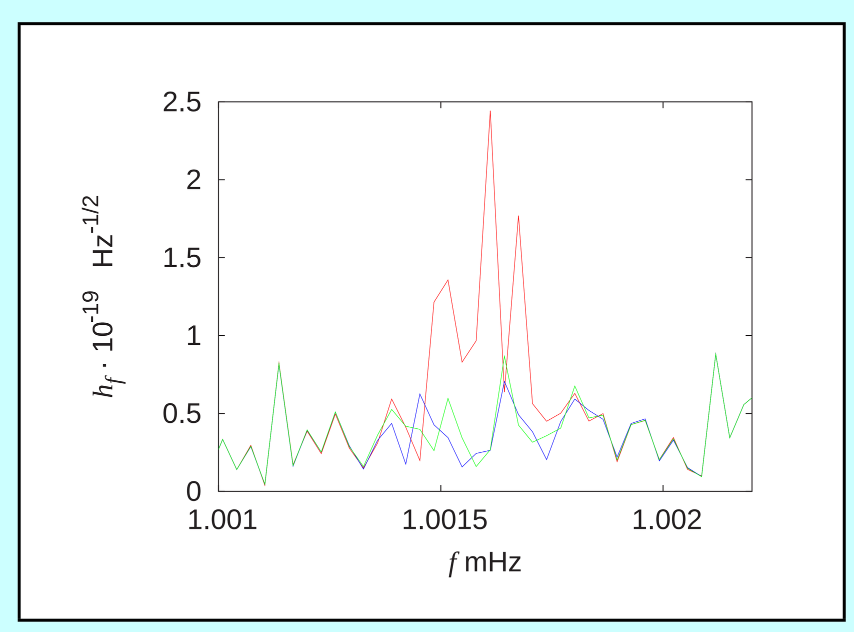
Additionally, we would like to compare and contrast Slice & Dice's performance to other galactic binary search procedures.

Highly Overlapping Signals

Consider two systems with signal-to-noise ratios 17 and 12, separated in frequency by $0.07 f_m$, in sky location by 90°, and with random orientations; their initial self-correlation matrix is

$$r_{1yr} = \begin{pmatrix} 1 & 0.090 \\ 0.090 & 1 \end{pmatrix} .$$

While their frequencies are nearly identical, these sources are largely separated on the sky and therefore have small cross-correlations.



The final comparison correlation matrix beteween the original signals and the estimated signals is

$$r_{1yr} = \begin{pmatrix} 0.94 & 0.11 \\ 0.06 & 0.99 \end{pmatrix} .$$

Slice & Dice was able to accurately identify the two signals.

References

[1] D. Hils, P. L. Bender, & R. F. Webbink, ApJ **360**, 75 (1990).

[2] S. E. Timpano, L .J. Rubbo, & N. J. Cornish, Phys. Rev. D **73**, 122001 (2006).